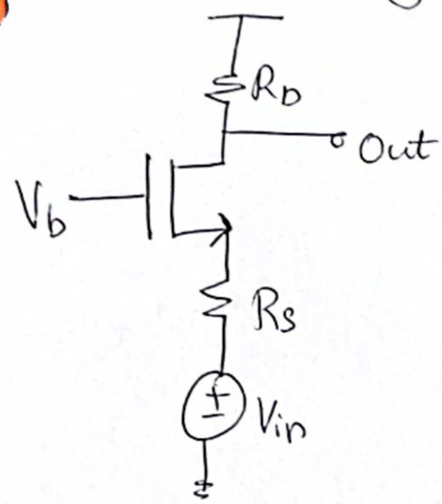
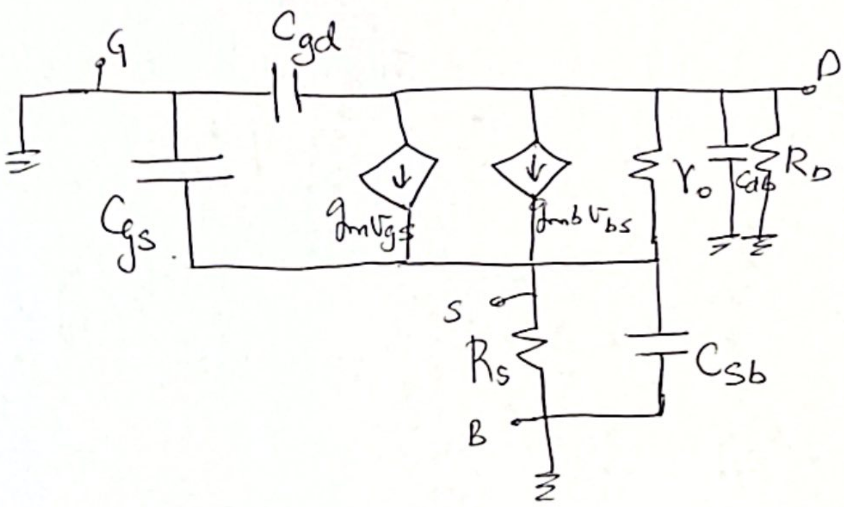
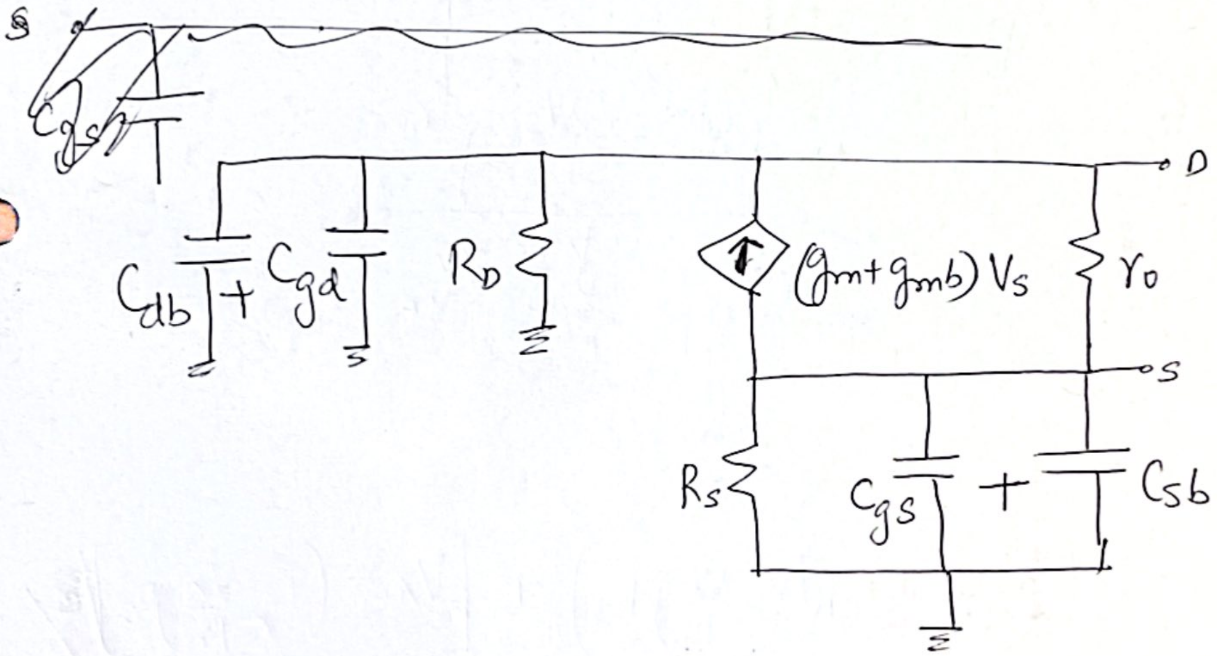
Lec23

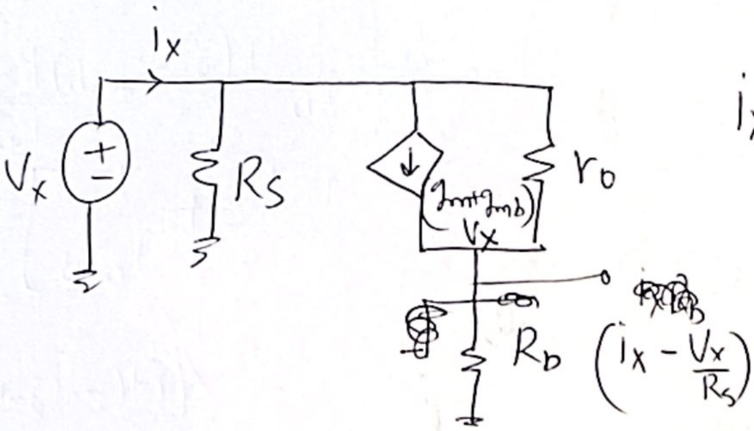
Common Gate







$C_{gs} + C_{sb}$:



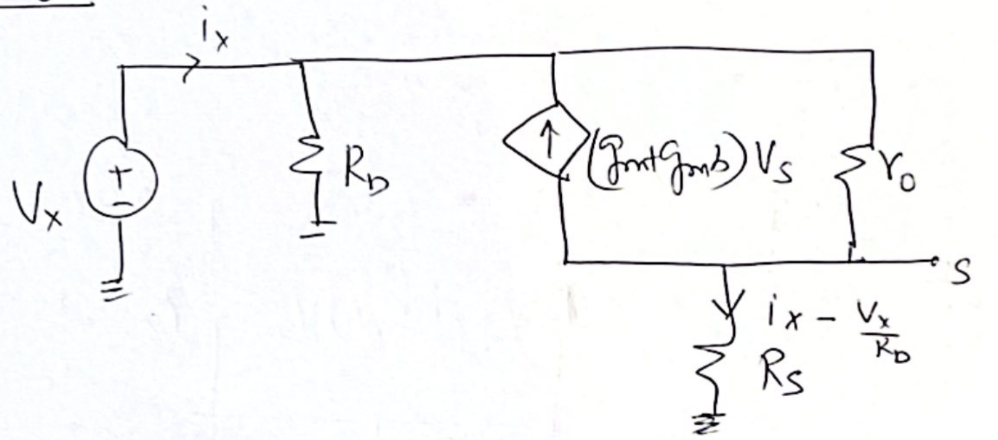
$$i_x = \frac{V_x}{R_S} + (g_m + g_{mb})V_x + \frac{V_x - i_x R_D}{r_o}$$

$$\left(i_x - \frac{V_x}{R_S}\right)$$

$$\Rightarrow V_x\left(g_m + g_{mb} + \frac{1}{R_S} + \frac{1}{r_o} + \frac{R_D}{r_o R_S}\right) = i_x\left(1 + \frac{R_D}{r_o}\right)$$

$$\Rightarrow R_S^o = \frac{R_S \parallel r_o \parallel \frac{1}{g_m + g_{mb}}}{1 + \frac{R_D}{r_o}} \simeq R_S \parallel \frac{1}{g_m + g_{mb}}$$

$C_{db} + C_{gd}$:



$$\Rightarrow i_x = \frac{V_x}{R_D} - (g_m + g_{mb})\left(\left(i_x - \frac{V_x}{R_D}\right)R_S\right) + \left[V_x - \left(i_x - \frac{V_x}{R_D}\right)R_S\right]\Big/ r_o$$

$$\Rightarrow i_x\left(1 + (g_m + g_{mb})R_S + \frac{R_S}{r_o}\right) = V_x\left[\frac{1}{R_D} + (g_m + g_{mb})\frac{R_S}{R_D} + \frac{1}{r_o} + \frac{R_S}{R_D r_o}\right]$$

$$\Rightarrow R_D^o = \left[\frac{1}{R_D} + (g_m + g_{mb})\frac{R_S}{R_D} + \frac{1}{r_o} + \frac{R_S}{R_D r_o}\right] \Big/ \left[1 + (g_m + g_{mb})R_S + R_S/r_o\right]$$

$$\Rightarrow R_D^{o} = \frac{R_D \,||\, \cancel{R_D\left(\frac{R_S}{g_m+g_{mb}}\right)} \,||\, \cancel{r_o} \,||\, \cancel{\frac{r_o R_D}{R_S}}}{1 + \cancel{(g_m+g_{mb})R_S} + \cancel{\frac{R_S}{r_o}}}$$

$$\simeq R_D$$

$$\Rightarrow \omega_{3dB} \simeq \frac{1}{\underbrace{(C_{gs}+C_{sb})\left(R_S \,||\, \frac{1}{g_m+g_{mb}}\right) + (C_{gd}+C_{db})(R_D)}_{\approx \cancel{\frac{1}{C_{gs}/g_m}} = \frac{g_m}{C_{gs}}}}$$

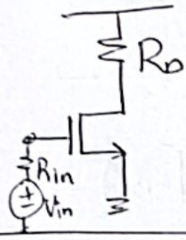
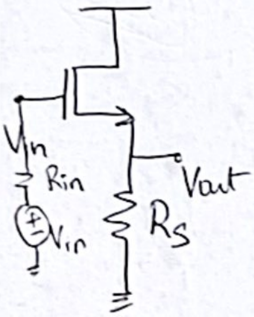
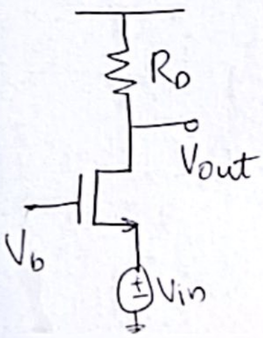
> Again no Miller effect!

$$> \omega_{3dB} \simeq \cancel{\frac{g_m}{C_{gs}}} \quad \frac{1}{R_D C_{gd} + C_{gs}\left(R_S \,||\, \frac{1}{g_m}\right)}$$

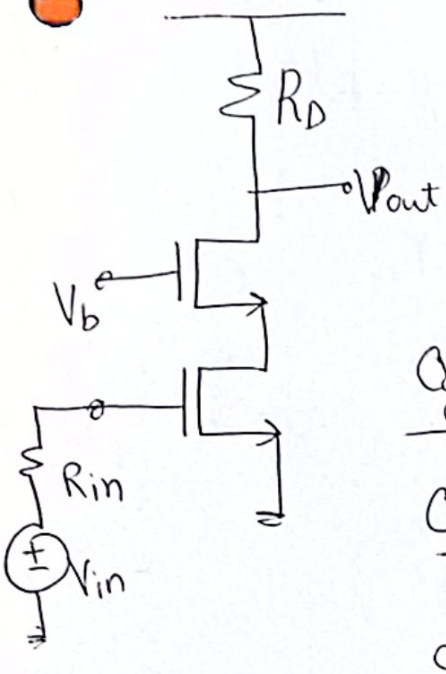
Summary

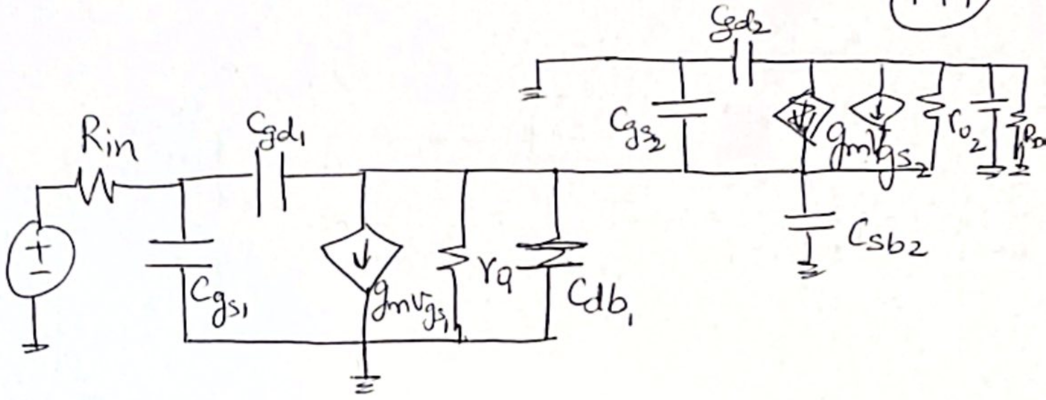
Gain of Common Gate if $R_{in} \neq 0$

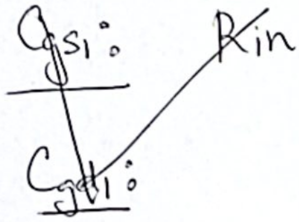
$$\approx \frac{(g_m + g_{mb}) r_o R_D}{R_D + r_o + R_{in}((g_m+g_{mb})r_o + 1)}$$

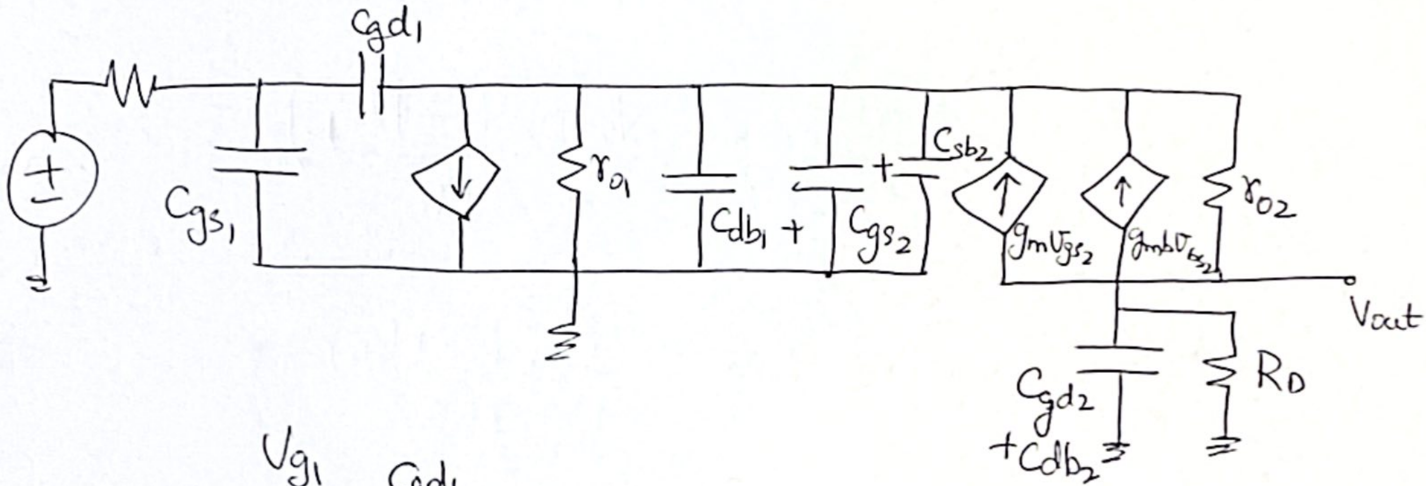
Type	Low freq. Gain	Bandwidth	Rin	Rout
Common Source 	(~~Assuming~~ $-g_m(r_o \parallel R_D)$ High Inverting	$\frac{1}{R_{in}(1+g_m R_D)C_{gd} + R_{in} C_{gs} + R_D C_{gd} + R_D C_{db}}$ Low (Miller)	∞	$\boxed{r_o \parallel R_D}$
Common Drain 	$\frac{g_m(r_o \parallel R_S)}{1+(g_m+g_{mb})(r_o \parallel R_S)}$ $\simeq 1$ Noninverting	$\frac{1}{R_{in}C_{gd} + \frac{C_{gs}+C_{sb}}{g_m+g_{mb}}}$ High (No Miller)	∞	$R_S \parallel r_m \parallel r_{mb} \parallel r_o$ $\simeq \boxed{R_S \parallel r_m}$
Common Gate 	High Noninverting $(g_m + g_{mb} + \frac{1}{r_o})(r_o \parallel R_D)$ $\simeq (g_m+g_{mb})(r_o \parallel R_D)$ Assuming $R_{in} = 0$	$\frac{1}{(C_{gs}+C_{sb})(R_{in} \parallel \frac{1}{g_m+g_{mb}}) + (C_{gd}+C_{db})R_D}$ $\simeq \frac{1}{R_D C_{gd} + C_{gs}(R_S \parallel \frac{1}{g_m})}$ High (No Miller)	$r_m \parallel r_{mb} \parallel r_o$ $\simeq \boxed{r_m}$	$\boxed{r_o \parallel R_D}$

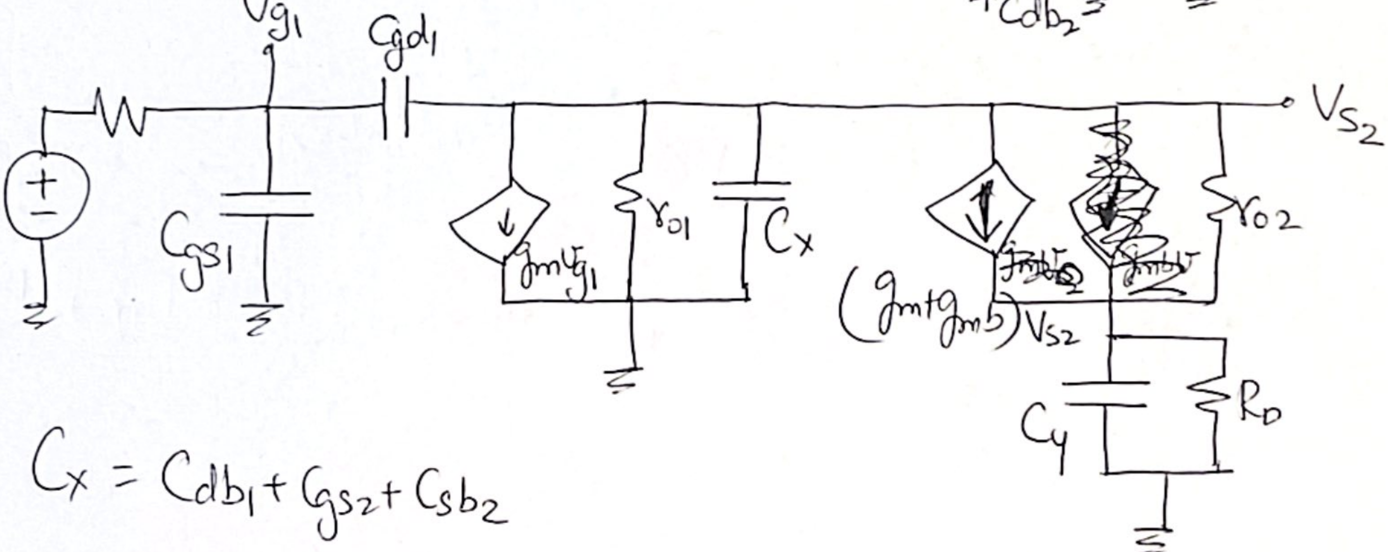
Cascode







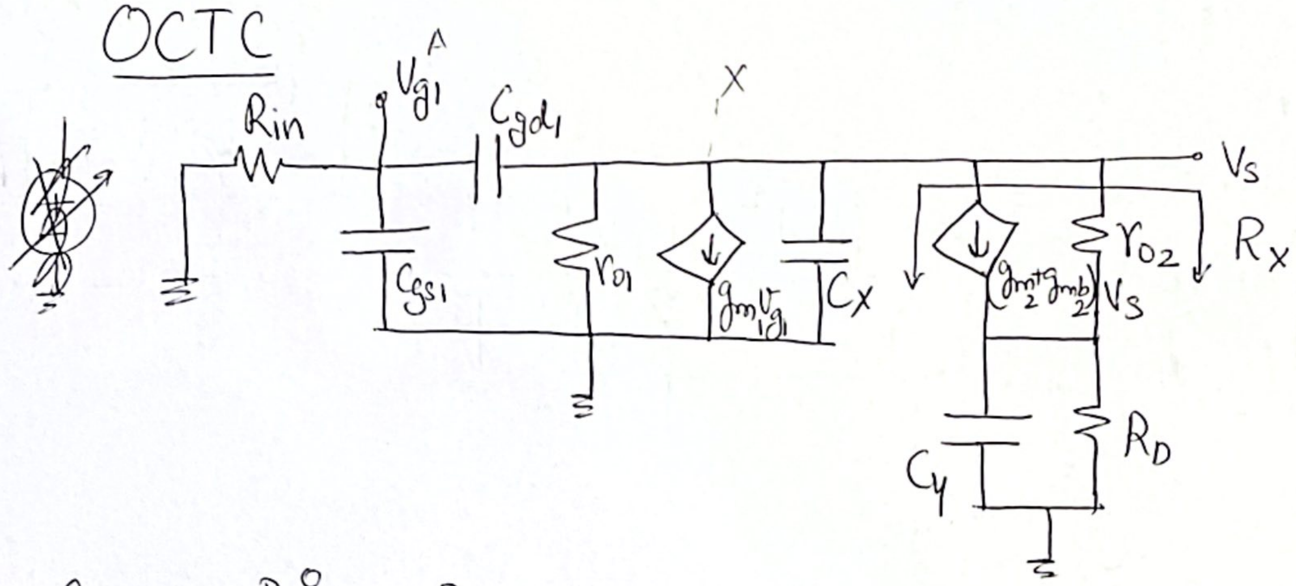




$$C_x = C_{db_1} + C_{gs_2} + C_{sb_2}$$

$$C_y = C_{gd_2} + C_{db_2}$$

OCTC



C_{gs1}: $R^{o}_{gs_1} = R_{in}$

C_{gd_1}: $$R_X = \frac{V_X}{I_X} = \frac{V_X}{(g_{m2}+g_{mb2})V_X + \left(\frac{V_X - I_X R_D}{r_{o2}}\right)}$$

$$\Rightarrow V_X\left((g_{m2}+g_{mb2})r_{o2}+1\right) = I_X(r_{o2}+R_D)$$

$$\Rightarrow R_X = \frac{r_{o2}+R_D}{(g_{m2}+g_{mb2})r_{o2}+1} \approx \frac{1}{g_{m2}+g_{mb2}}$$

Combining with $r_{o1} \Rightarrow R^{o}_{gd_1} = g_{m1}R_{in}R_X' + R_{in} + R_X'$

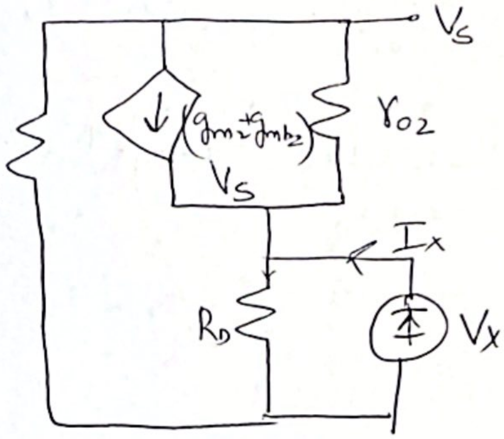
Where $R_X' = R_X \| r_{o1}$

$$\Rightarrow R^{o}_{gd_1} = \frac{g_{m1}R_{in}}{g_{m2}} + R_{in} + \frac{1}{g_{m2}} \cong 2R_{in}$$

↳ Dropped from $g_m R_o$ to 2!

C_x : $\quad r_{o1} \| R_x = R_x' = \dfrac{1}{g_{m2}+g_{mb2}}$

C_y :



$$I_x - \frac{V_x}{R_D} = -(g_{m2}+g_{mb2})V_s + \frac{(V_x - V_s)}{r_{o2}}$$

$$V_s = \left(I_x - \frac{V_x}{R_D}\right) r_{o1}$$

$$\Rightarrow I_x - \frac{V_x}{R_D} = -(g_{m2}+g_{mb2})\left(I_x - \frac{V_x}{R_D}\right) r_{o1} + \frac{V_x}{r_{o2}} - \left(I_x - \frac{V_x}{R_D}\right)\frac{r_{o1}}{r_{o2}}$$

$$\Rightarrow I_x\left(1 + (g_{m2}+g_{mb2})r_{o1} + \frac{r_{o1}}{r_{o2}}\right) = V_x\left(\frac{1}{R_D} + \frac{r_{o1}}{R_D}(g_{m2}+g_{mb2}) + \frac{1}{r_{o2}} + \frac{r_{o1}}{R_D r_{o2}}\right)$$

$$\Rightarrow R_x = \frac{1 + \frac{r_{o1}}{r_{o2}} + (g_{m2}+g_{mb2})r_{o1}}{\left(\frac{1}{R_D} + \frac{r_{o1}}{R_D}(g_{m2}+g_{mb2}) + \frac{1}{r_{o2}} + \frac{r_{o1}}{R_D r_{o2}}\right)} \simeq \frac{g_{m2} r_{o1}}{\frac{g_{m2} r_{o1}}{R_D}} \simeq R_D$$

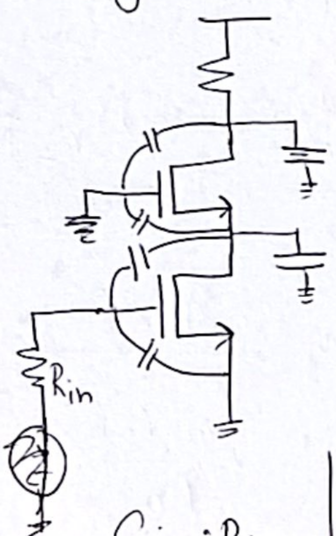
$$\omega_{3dB} = \frac{1}{R_{in} C_{gs1} + \left[R_{in}\left(1 + \frac{g_{m1}}{g_{m2}+g_{mb2}}\right) + \frac{1}{g_{m2}+g_{mb2}} \right] C_{gd1} + \frac{(C_{db1} + C_{gs2} + C_{sb2})}{g_{m2}+g_{mb2}} + R_D (C_{gd2} + C_{db2})}$$

$$\simeq \frac{1}{C_{gs1} R_{in} + \left(2 R_{in} + \frac{1}{g_{m2}}\right) C_{gd1} + \frac{C_{gs2}}{g_{m2}} + C_{gd2} R_D}$$

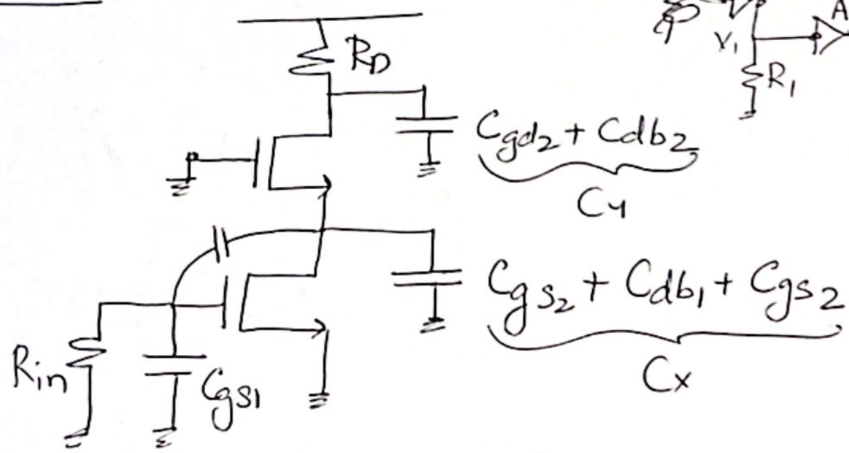
Only 2 insted of Miller!

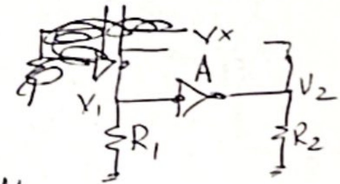
$\Rightarrow$ Wide band.

Doing this by inspection!



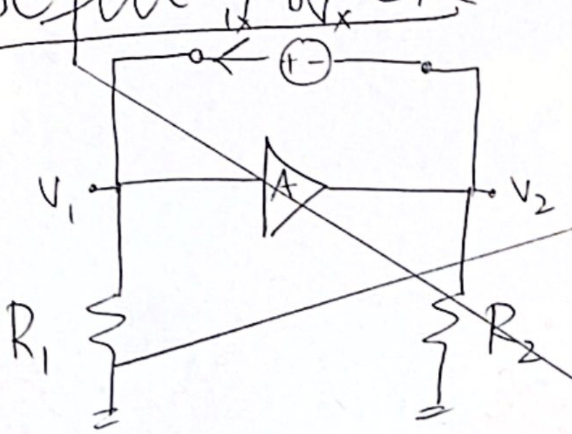
$\rightarrow$





$C_{gs1} : R_{in}$	C_{gd1} : $R_{in} + \frac{1}{g_{m2}} + \frac{g_{m1} R_{in}}{g_{m2}} \simeq 2R_{in}$	$C_X : \frac{1}{g_{m2}}$	$C_Y = R_D \,\|\, g_{m2} r_a r_{o2} = R_D$

Useful Trick

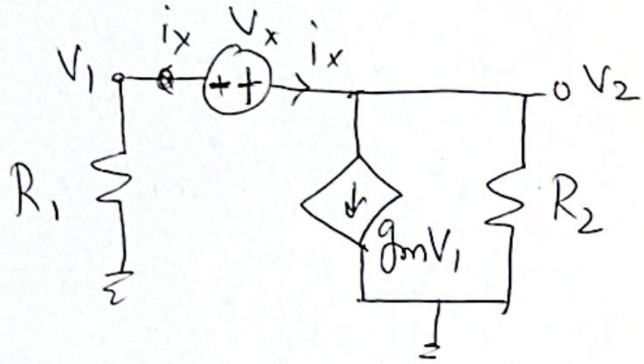


$$V_2 = A V_1$$

$$i_x = \frac{V_1}{R_1} = -\frac{V_2}{R_2}$$

$$V_x = V_1 - V_2$$

$$= i_x R_1$$



$$i_x = g_m V_1 + \frac{V_2}{R_2} \qquad V_2 - V_1 = V_x$$

$$\frac{V_1}{R_1} = -i_x$$

$$\Rightarrow \left.\begin{aligned} V_2 &= V_x \cancel{+} - i_x R_1 \\ V_1 &= -i_x R_1 \end{aligned}\right\} \Rightarrow i_x = g_m(-i_x R_1) + \left(\frac{V_x - i_x R_1}{R_2}\right)$$

$$\Rightarrow i_x\left(1 + g_m R_1 + \frac{R_1}{R_2}\right) = \frac{V_x}{R_2}$$

$$\Rightarrow \boxed{R_x = R_1 + R_2 + g_m R_1 R_2}$$